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Photoperiod Induction, Gibberellic Acid, Mulch And Row Cover Effects On Fresh Cut Flower Production Of Three Rudbeckia Hirta L. Cultivars

Kieran Johnson

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PHOTOPERIOD INDUCTION, GIBBERELLIC ACID, MULCH
AND ROW COVER EFFECTS ON FRESH CUT FLOWER
PRODUCTION OF THREE *Rudbeckia hirta* L.
CULTIVARS

By

Kieran A. Johnson

A Dissertation
Submitted to the Faculty of
Mississippi State University
in Partial Fulfillment of the Requirements
for the Degree of Doctor of Philosophy
in Horticulture
in the Department of Plant and Soil Sciences

Mississippi State, Mississippi

May 2006

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MULCH AND ROW COVER EFFECTS ON FRESH CUT
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Photoperiod studies have been the subject of research projects for decades. In such studies, *Rudbeckia hirta* L. has often been chosen due to its early recognition (1920's) as a long day plant. *R. hirta* has also been the subject of experiments to evaluate the timing of floral initiation in regard to the exogenous application of phytohormones. Former projects have been primarily directed toward understanding floral initiation mechanisms of long day plants for the production of greenhouse grown crops. Photoperiod manipulation and exogenous application of

phytohormones have not been used to the same extent for field-grown fresh flower research.

Three experiments were conducted in the spring of 2006 to determine if time to flowering could be manipulated for field grown *R. hirta* without subsequent loss of quality. In the first experiment, two cultivars, *R. hirta* 'Indian Summer' and *R. hirta* 'Irish Eyes' were given 4-hour night interruption (NI) using a 60-watt incandescent bulb during greenhouse production. Night interruption lasted for 0, 21, 28 or 35 days. Prior to field transplanting, GA₃ was exogenously applied once to transplants at rates of 0, 150 or 300 ppm.

For 'Indian Summer', early flowering was achieved with 35 days of NI alone or with either rate of GA₃ plus 21-day NI. Increasing GA₃ to 300 ppm improved stem length. For 'Irish Eyes', 35-day NI alone was equally effective at producing early blooms compared to 35-day NI and either rate of GA₃.

The second experiment included *R. hirta* 'Irish Spring' grown in the greenhouse then given 0 or 35 days NI as in the first experiment. Then, seedlings were transplanted to the field in plots with various combinations of polyethylene row cover, black plastic mulch and bare

ground. Only plants receiving 35-day NI flowered during the test. Polyethylene row cover increased the percentage of blooms harvested.

The third experiment measured the vase life of blooms harvested from experiments one and two. Treatments did not affect vase life of blooms. Mean postharvest life for all treatments was greater than 7 days.

DEDICATION

This manuscript is dedicated to Joyce Ann, my loving wife. Without her support and encouragement this would not have been possible.

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CHAPTER I

INTRODUCTION

Fresh cut flower production is an important part of American agriculture. In the year 2000, wholesale value of fresh cut flower production reached 4.57 billion dollars in the United States (Nelson, 2003a). However, Mississippi has had no significant share in this industry largely due to a lack of knowledge regarding fresh flower production. That is beginning to change as both university professionals and flower growers have begun to research and explore fresh flower production and marketing techniques (Sloan and Harkness, 2005).

One of the most important aspects of production is the harvest of high quality floral crops at a time when the market reflects consistent consumer demand. Such demand typically peaks around major holidays such as Valentine's Day and Mother's Day (Monthly Retail Trade Survey, 2005).

Rudbeckia species are well known and widely used as ornamental bedding plants and fresh cut flowers. *Rudbeckia* spp. have the potential to produce multiple, marketable

floral stems. Once flowering begins, *Rudbeckia hirta* L. produces blooms until frost, however, flowering occurs outside of peak market demand (Monthly Retail Trade Survey, 2005).

Rudbeckia species are of the sunflower family (Asteraceae) (Harkess and Lyons, 1994a). The *Rudbeckia* genus consists of approximately 25 annual, biennial or perennial herbaceous species native to North America. The attractive *Rudbeckia* inflorescence is composed of a prominent central dark brown cone (disc florets) with golden-yellow ray florets. Some species and cultivars have varying amounts of brown on the petals.

Previous research suggests that photoperiod induction by means of night interruption or day length extension, and the exogenous application of naturally occurring phytohormones may affect the timing of floral initiation of *Rudbeckia* spp. and may affect floral quality (Murneek, 1936; Tanimoto and Harada, 1985; Harkess and Lyons, 1994b). It is proposed that these two factors be examined together for the purpose of shifting the timing of fresh cut flower harvest from midsummer to early May while maintaining or improving floral quality.

If *Rudbeckia* cultivars can be forced to bloom earlier in the year, around Mother's Day, without a significant loss in floral quality, demand for this crop may increase, production volume enlarged and profit potential improved.

Photoperiod studies have been the subject of horticultural research projects for decades. *Rudbeckia* was used regularly for research once it was discovered to be a long-day plant in the 1920's (Garner and Allard, 1925). *Rudbeckia* has also been the plant of choice in experiments to evaluate the timing of floral initiation in regard to the exogenous application of certain phytohormones and cytokinins (Harkess and Lyons, 1994b).

These projects were primarily directed toward understanding floral initiation mechanisms of long day plants as it applies to production of greenhouse grown nursery crops. Photoperiod manipulation and exogenous applications of phytohormones have not been used to the same extent for fresh cut flower production.

Marketing opportunities exist for Mississippi field grown flowers even though production is relatively new to the state. These opportunities are further advanced if floral initiation timing can be manipulated for earlier harvest and floral quality maintained or enhanced with the use of photoperiod induction and phytohormone application.

The objectives of this study were to 1) determine whether long day cultivars, *Rudbeckia hirta* 'Indian Summer' and 'Irish Eyes', can be manipulated by photoperiod and exogenous application of GA₃ to initiate blooms earlier than normal and of quality suitable for the floral industry; 2) examine the effect of photoperiod induction, mulch and row cover on *Rudbeckia hirta* 'Irish Spring' relative to earliness to bloom and floral quality; and 3) determine if blooms produced under certain growing conditions have sufficient postharvest life for use in floral markets.

CHAPTER II

REVIEW OF LITERATURE

Effect of Photoperiod

Beginning in the 1920's, W. W. Garner and H. A. Allard conducted research pioneering our understanding of photoperiodism. They reported a number of species whose reproductive activity was either initiated or inhibited depending on the length of day. Some species were noted to respond reproductively to short days and others to long days. Those responding reproductively to short days were termed "short day" and the second group as "long day" plants (Garner and Allard, 1924).

Another experiment conducted by Garner and Allard (1924) demonstrated that *Rudbeckia bicolor* Nutt. responded to an 18-hour photoperiod obtained with a combination of natural and incandescent (100-watt) light. Under this regime, plant axis development began within 2 weeks of treatment initiation. Long day plants were subsequently described as those that "remain in the leaf-rosette stage, without stem elongation when exposed to a short light

period but are capable of developing flowering stems under the influence of a longer daily light period". Plants in this group exposed to relatively long days resulted in stem elongation followed by flowering. Garner and Allard reported light intensities as low as 5 foot-candles ($1.1\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$) were "capable of exercising a definite formative action on floral initiation" (Garner and Allard 1924).

Murneek (1936) found that *R. bicolor*, considered synonymous with *R. hirta* var. *pulcherima* Farw., will not bolt and flower unless the plants have been exposed to day lengths greater than 12 hours. He reported the effect of day length on stem elongation and flowering as "distinctly separable". Seedlings exposed to 10 to 13-hour photoperiods followed by 7-hour days resulted in varied floral initiation depending on light duration. Plants either flowered normally under the longest photoperiod or formed "vegetative" flowers with green petals and vegetative stamens and pistils, or had no flowers at all depending on the length of photoperiod prior to being moved to short day treatment.

Murneek (1936) described the phenomenon as "photoperiodic inhibition". Results indicated that long

day plants, including *Rudbeckia* spp., require a certain "dosage" or number of days with a minimum number of lighted hours to fully bring about the initiation of reproductive growth. He suggested "the mechanism of photoperiodism is not trigger-like in its action (and) that possibly a certain substance or substances are produced gradually, the quantitative accumulation of which results eventually in the development of reproductive organs."

Murneek's (1936) results indicated that stem elongation could not be induced (triggered) but occurs and is sustained only under long photoperiods of certain duration. Stem elongation stopped when plants were moved from long to short days.

Murneek later quantified the day length requirement for *R. bicolor*. By observing the normal progression of plant growth and development from November to mid-July he found, in mid-March, when day length was approximately 12-hours, plants began to show signs of reproductive development. Plants receiving less than a 12-hour photoperiod remained in the rosette stage of development. He also found that plants exposed to 14-hour days from the seedling stage on, developed normally (Murneek, 1940)

In a similar study, Greulach (1942) reported, "Once certain plants initiated flower primordia as a result of photoperiodic induction and then transferred to photoperiods unfavorable to floral initiation, floral development may continue as an after-effect of induction or it may be inhibited. If inhibited, the plant may return to vegetative growth." Vegetative flowers and/or lack of blooms when returned to unfavorable light conditions were apparently caused by insufficient light duration. This resulted in somewhat of a reversion to vegetative growth and development. Cessation of stem elongation after induction followed by transfer to short photoperiods occurred even if plants eventually bloomed.

According to Kochankov and Chailakin (1986), most *Rudbeckia* are obligate long day plants with a minimum critical day length of 10 to 14.5 hours depending on species. Day lengths shorter than a critical photoperiod resulted in vegetative growth as a rosette. Long photoperiods (12 hours or more) give rise to elongation of the main stem. Their experiment demonstrated that stem elongation occurred earlier when plants were exposed to a longer photoperiod. Plants observed for 91 days under short photoperiods (8-12 hr) failed to form flower buds.

However, flower buds formed earlier under photoperiods longer than those critical. It was also noted that the number of nodes on the main stem were the same under different photoperiods and photoperiod affected only the elongation of internodes (Kochankov and Chailakin, 1986).

Work with *R. hirta* 'Marmalade' (Orvos and Lyons, 1989) supported Murneek's discoveries. That is, stem elongation and floral induction in *Rudbeckia* were shown to be two separate phenomena controlled by photoperiod. *Rudbeckia* height at flowering depends on previous exposure to long days.

As plants receive longer periods of uninterrupted long days the stem-effect of "photoperiodic inhibition" diminishes. In their experiment, Orvos and Lyons used ambient light and 4-hour night interruption via 60-watt incandescent light to provide long days. Results indicated the longer the plant perceives the inductive photoperiod the faster it will come into flower. This is true regardless of whether measured in time from seeding or from start of long day exposure. *Rudbeckia hirta* required several days of photoperiodic induction with a minimum of 4 days for floral initiation but longer periods were required for normal growth and development

Floral initiation is affected by day length extension, termed "limited induction photoperiod" (LIP). Damann and Lyons (1993) defined LIP as an expansion of Murneek's (1936) concept of "photoperiodic inhibition". LIP is "a method whereby the plant is given the minimum number of inductive cycles to initiate flowering before transfer back to non-inductive conditions".

When to begin LIP is a very important question. Murneek (1940) noted that leaves assumed a more vertical position as the first sign in the change in development, that is, the induction of the reproductive growth stage. The term "juvility" came to be used to describe the level of sensitivity to photoperiodic induction. Usually, the seedling has to reach a certain size before flowers can be formed. Others reported that size may be quantitatively expressed as "the minimum number of leaves laid down before flower initiation" (Doorenboos and Wellensek, 1959). Therefore, a period of juvility may be described physiologically as a time when a plant is not sensitive or not as sensitive to conditions that promote floral initiation. This is considered common in plants (Daman and Lyons, 1993; Bernier et al., 1981).

Murneek reported (1940) that seedlings exposed continually to long photoperiod (14-hour day) developed much the same as those grown under natural day length. Long days shortened the time to flowering. Final height and appearance were very similar as when plants were grown under natural photoperiod length.

Orvos and Lyons (1989) reported that peak sensitivity to photoperiodic induction seemed to occur after the plant has approximately 12 true leaves. Work by Celik (1996) demonstrated that *R. hirta* responded to inductive conditions at leaf stages less than 14 leaves. The minimum days to flower from seeding decreased if plants were moved to long days earlier than the 14-leaf stage.

Harkess and Lyons (1993a) revealed that sensitivity to photoperiodic induction appears to increase with age. Plants were grown under short day conditions until they reached 14 to 16 true leaves then transferred to long day conditions. They found, through histological examination, *R. hirta* required 18 long days for floral development to begin. However, floret primordia did not initiate even after 20 long days.

Additional studies by Harkess and Lyons (1993c) were conducted to examine the response of *R. hirta* to limited

inductive photoperiod through specific examination of meristematic tissue. Plants were grown to 14-leaf stage under short days then placed in long days for varied duration before transfer back to short days. When grown to anthesis, plant height and branch number increased as the number of inductive cycles increased. Plants receiving 24 or more long days reached anthesis earlier than plants receiving fewer long days. When examined microscopically, plants receiving only 4 long days were found to have stalled at early floral initiation. After receiving 12 long days, meristems continued to initiate flowering when returned to short days. Regardless of lighting regime, once the involucral bract primordia initiated, floral development continued under either short or long days.

Runkle and others (1998) tested six long-day species, including *Rudbeckia fulgida* Ait. 'Goldsturm' under various night interruption and cyclic lighting treatments. Photoperiods were 9-hour natural days with night interruption provided by incandescent lamps during the middle of the dark period for various durations including two cyclic treatments. Two groups of *R. fulgida* 'Goldsturm' included chilled or unchilled plants. As the length of the uninterrupted night break increased,

flowering percentage, uniformity and number and plant height increased and time to flower decreased. Minimum levels of night interruption were 4 hours for unchilled *R. fulgida* and 1 hour for chilled plants receiving 8 weeks of cold. Chilled plants flowered more rapidly than unchilled ones. Additionally, cyclic lighting treatment of 6 minutes on and 24 minutes off for 4 hours produced flowering similar to that under a continual 4-hour night interruption for the cold treated *R. fulgida* 'Goldsturm'.

Further studies were conducted by Runkle and others (1999) to compare the effect of photoperiod and cold treatment for regulating flowering of *R. fulgida* 'Goldsturm'. Plants received 1 of 7 photoperiods and either 0 or 15 weeks of cold treatment. Non-cooled 'Goldsturm' remained vegetative under photoperiods of less than or equal to 13 hours. All plants flowered under photoperiods of greater than 14 hours or with a 4-hour night interruption. A cold treatment was not required to induce flowering of 'Goldsturm' but chilled plants flowered sooner than unchilled. Cold treatment may have increased the sensitivity of 'Goldsturm' to photoperiod. Application of a cold treatment also reduced the number of new nodes developed below the first inflorescence. A cold treatment

had little or no influence on flowering percentage, uniformity, flower number, plant height or vigor. Yuan (1998) reported, however, that a population of 'Goldsturm' must have an average of at least 10 nodes per plant for relatively complete flowering (Yuan, 1995).

In a study of 6 long-day perennials, Hamaker and others (1996) found that day-length extension and four hour night interruption work equally well. Electrical costs may be the determining factor regarding which method of photoperiod induction is used (Hamaker et al., 1996).

Later research used night interruption lighting (NI) for photoperiodic induction in a southern nursery setting. NI began at different times in late winter and early spring and was compared with natural day length for several containerized herbaceous perennials including *R. fulgida* 'Goldsturm'. In both years of the study, night interruption lighting resulted in more rapid floral initiation and development in *Rudbeckia fulgida* 'Goldsturm' compared to natural photoperiod. Flowering was accelerated 26-46 days in the first year and by 51-75 days in the second. Plant height also increased under all NI treatments, however, plant quality lessened (Keever 2001).

In a study of the effect of lamp types for photoperiod induction, an irradiance of $1.0 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ from any lamp was sufficient for flowering in *Coreopsis verticillata* L. 'Moonbeam'. The time to flower at irradiances above saturation points were not significantly different between lamp types for all species tested. *Campanula carpatica* Jacq. 'Blue Chips' and *Coreopsis grandiflora* Hogg ex Sweet 'Early Sunrise' stems were significantly longer under incandescent lamps than any other treatment (Whitman et al., 1998).

Gibberellin Effect

Exogenous applications of gibberellins have been reported to cause stem elongation and subsequent flower bud formation under short day conditions (Tanimoto and Harada, 1985). Bunsow and Harder (1957) applied four drops of 100 mg/l GA to shoot tips and found that this treatment induced bolting and flowering in *R. bicolor* and *R. hirta*.

Kochankov and Chailaykan (1986) reported the effect of a variety of chemical compounds on stem growth and flowering of *R. bicolor*. Compounds tested included phytohormones (gibberellins, auxins, cytokinins, abscisic acid), natural and synthetic growth retardants and

inhibitors, nucleic metabolites, vitamins, phenolic compounds, organic acids and antibiotics.

Under short day conditions, gibberellins were the only compounds that induced stem growth and formation of flowers. Under long days, a variety of chemical compounds may either stimulate or hinder stem growth and flowering. Seven gibberellins were tested on *R. bicolor*. GA₃ and GA₁ were the most active in causing stem elongation and flowering (Kochankov and Chailaykin, 1986).

Research demonstrated that the most effective method of treatment with GA is direct administration to the plant (i.e. spraying the leaf surface or applying drops of solution containing surfactant to the shoot tip). Researchers employed daily applications of 24 µg of GA₃ per shoot tip administered as a drop of a 50 mg/l solution. This solution, administered for 12 days under short day conditions had virtually the same effect on stem growth and flowering in 4-month old plants as did 12 days of induction by long days. Conversely, a one-time application of 10 mg/l GA₃ on 6-month old *Rudbeckia bicolor* plants stimulated leaf growth but did not significantly affect stem growth or lead to flower initiation (Podol'nyi and Chetverikov, 1987)

GA₃ treatments have been shown to increase the number

of blooms in *Aglaonema* breeding stock (Henny, 1983).

Gibberellic acid is known to stimulate elongation of plant cells resulting in taller and larger leaves without inhibiting development. Researchers found that GA₄ + GA₇ may enhance the long day effect on the apical meristem of *Rudbeckia* but axillary meristem may remain unaffected. They found it significantly decreased days to terminal inflorescence anthesis (Harkess and Lyons, 1994b).

Gaillardia x *grandiflora* cultivars 'Dazzler' and 'Goblin' were induced to flower under long days with applications of GA₄ plus GA₇. GA apparently substituted for long days and promoted flowering under short days in the same time required by untreated, photoperiodically induced plants (Evans and Lyons, 1988)

Row Cover/Mulch Effect

Traditionally, row covers have been used to increase earliness in vegetable crops (Hochmuth et al., 2000). Use of plastic film mulches in vegetable crops have been shown to result in higher yields, earlier harvests, improved weed control and more efficient use of water and fertilizers (Lamont, 1999).

Cushman and others (2002) found that black plastic mulch and black plastic mulch with row covers produced higher yields than bare ground production of tomatoes (*Lycopersicum esculentum* Mill.) planted in early spring.

Plastic mulches (silver, gray, or black) used in tomatillo (*Physalis ixocarpa* Brot. ex Hornem) production had little effect on plant growth during the first 30 days after transplanting three tomatillo cultivars. There were no significant differences in fruit yields (Mills et al., 2005).

Black plastic mulch controlled most weeds but did not warm the soil as well as clear mulch in strawberry (*Fragaria x ananassa*) crop response studies. Black mulch allowed the least amount of photosynthetically active radiation to pass through when compared to clear or colored mulch. Under conventional production practices there were no significant yield differences for strawberries grown on black plastic mulch and bare ground (Johnson and Fennimore, 2005).

Black mulch and slit polyethylene tunnels have been used in bell pepper research. Row covers were determined to advance anthesis and delay harvest dates on the lower nodes and increased the duration of maturation over all

branches and nodes. However, row covers did not influence total fruit yield (Gaye et al., 1992).

In two of three years, plots of bell pepper (*Capsicum annuum* L. var. *annuum* 'California Wonder') with black plastic mulch had marketable yields lower than those from other treatments (Roberts and Anderson, 1994).

In a comparative study of various mulches for fresh-market basil (*Ocimum basilicum* L.), yields were highest with black plastic mulch versus other mulch types (Davis, 1994).

For tomatoes, total yield of those grown on black plastic mulch was increased by 95% over the control for two cultivars and two planting dates. Black plastic mulch also increased early production in one of two cultivars (Hoover et al., 1992).

In a comparison of colored mulch affecting yield and earliness of tomato, black plastic mulch plots had a higher percentage of early-harvested fruit than colored mulches or bare ground. However, total yield on black plastic mulch was the lowest of 8 mulch treatments (Brown et al., 1993).

Postharvest Life

For flowers to be considered for use as fresh-cut they should have a minimum postharvest vase life of 7 days. Short postharvest life may limit market acceptability (Stevens, 1998).

Developmental stage at time of harvest is important for maximizing post harvest life of fresh cut flowers. For *Rudbeckia* spp., flowers should be fully open with the first ring of disk florets open. Compositae family flowers are often harvested when the outer petals are fully developed and only one ring of inner florets are showing pollen. Cut flowers should be harvested when fully turgid, usually in the morning, since water content and coolest tissue temperature of flowers is critical to postharvest life. Most cut flowers should be immediately placed into buckets of water and hydrating solution. Once cut, *Rudbeckia* stems may be stored at 2-5 °C (Dole and Wilkins, 2005).

Armitage and Laushman (2003) recommend that, in general, members of Asteraceae, including *Rudbeckia*, be harvested when blooms are beginning to open. Post harvest life is expected to be 7-10 days in a floral preservative although some may persist longer. Cut stems can be stored at 2-5 °C but storage is not recommended.

CHAPTER III

MATERIALS AND METHODS

Three *Rudbeckia hirta* cultivars were used in this study. The first, 'Indian Summer' was chosen by the Association of Specialty Cut Flower Growers (ASCFG) as the fresh cut flower of the year in 2000. Greenhouse growers have produced it for the bedding plant market in the southeastern U.S. The inflorescence has black disk and golden-yellow ray flowers. Peak bloom time (early summer to fall) occurs when consumer demand for fresh cut flowers is relatively low (Monthly Retail Trade Survey, 2005).

The second, *R. hirta* 'Irish Spring', is a relatively new cultivar, complimentary to 'Indian Summer', but with a green "eye" (disk flowers). It has the same excellent qualities of 'Indian Summer' including thick, sturdy stems. It received the Fleuroselect Quality Mark for 2003.

The third cultivar, *R. hirta* 'Irish Eyes', has a green cone of disk flowers setting it apart from the traditional "black-eyed Susan". Although very attractive, it is not widely used as a fresh cut flower.

Experiment I: Photoperiod Response and Exogenous GA₃**Application**

Photoperiodic induction and exogenous applications of GA₃ were used to determine the effect on stem length, flower size and quality.

Transplants of *R. hirta* 'Indian Summer' and *Rudbeckia hirta* 'Irish Eyes' were grown in 128-cell (25 ml/cell) trays (T.O. Plastics, Clearwater MN) and received at MSU North Farm on 8 February 2005. 'Indian Summer' and 'Irish Eyes' transplants had been grown in a commercial greenhouse near Dallas, Texas. Seeds were sown in mid-October (Week 42) and mid-November (week 46), respectively, and grown in an unheated greenhouse (cold frame). Transplants were potted into 3.5-inch pots (T.O. Plastics, Clearwater, MN) with 515 ml volume Sungro LA4 Mix Aggregate Plus (Sungro Horticultural, Bellevue, WA 98008) on 9 February 2005.

Newly potted plants were greenhouse grown at the MSU Plant Science Research farm until field transplanted. Plants were fertilized during greenhouse production with water soluble 20-10-20 (Scott's Peat Lite Special, Scotts-Sierra Horticultural Products Company, Marysville, OH) at alternate waterings. Plants were drenched with fungicides

Subdue Maxx (Syngenta Professional Products Greensboro, NC) and Terraclor (Crompton Corporation Middlebury, CT 06749) at label rates.

The greenhouse was sub-divided (north-south) by a retractable curtain, approximately 2.5 meters tall, which served as a light barrier. This created an east side and a west side. Plants on the west side of the curtain received ambient light only. On the east side, plants received ambient light plus a four-hour night interruption providing approximately 16 total daily hours of light with the aid of 60-watt incandescent bulbs. Bulbs were suspended about 91cm (36 inches) above the plants. An automatic timer turned the lights on at 6:30 p.m. and off at 10:30 p.m. Light treatments included 0, 21, 28 and 35 days of night interruption (NI). Light meter readings indicated an average of $1.6 \mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$ just above plant height directly under the bulbs and $1.0 \mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$ between bulbs. Light intensity on the dark side of the barrier measured an average of $.01 \mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$.

The 35-day night interruption treatment began on 24 February 2005. At this time, 216 plants of each cultivar were moved to the lighted-side of the barrier. As this stage of the experiment began, the light barrier was closed

each day after sunset and before 6:30 p.m. and re-opened shortly after sunrise each morning.

The next two consecutive weeks, additional groups of 216 plants were moved into the lighted section of the greenhouse to obtain 28-day and 21-day light treatments. The control group remained on the "unlit" side of the barrier for the duration of the greenhouse phase of the experiment. Night interruption ceased on 30 March 2005.

Exogenous applications of GA₃ (Pro-Gibb T & O, Valent BioSciences Corporation, Libertyville, IL) were applied 29 March 2005. Plants receiving 150 or 300 ppm GA solution were moved to a nearby greenhouse for treatment to prevent contamination of non-target plants. GA solution was mixed at label rates by adding 2.1 ml Pro-Gibb T & O per 8 ounces of water (300 ppm) and 1.05 ml Pro Gibb T & O per 8 ounces of water (150 ppm). Applications were made with a small spray bottle adjusted to deliver a fine mist. Each plant received approximately 9.6 ml, regardless of plant size consisting of 3 puffs of solution from 4 directions for a total of 12 puffs per plant. Prior to application, plants were freshly watered and foliage was dry. Each application was made between 10:00 a.m. and 12:00 p.m. A corresponding amount of water was applied as mist to untreated plants.

A fungicide, Decree (SePro Corporation, Carmel, IN), was applied on 24 February 2005 for botrytis control. Talstar Flowable Insecticide/Miticide (FMC Corporation Agricultural Products Group, Philadelphia, PA) was applied to control spider mites on 3 March 2005 and again on 10 March 2005. Daily temperature readings were recorded by an automated system. Tissue samples were taken and analyzed once during the course of greenhouse production. Prior to removing plants to the field, twelve plants from each treatment combination were measured for height comparison.

Transplanting to field plots took place at the Northeast Branch Experiment Station in Verona, MS on 1 April 2005 and at Mayhew Tomato Farm in Mayhew, MS on 5 April 2005. A randomized complete block design with 4 replications was employed for statistical analysis. Plants were transplanted by hand into Savannah sandy clay loam at Verona and Kipling silty clay loam at Mayhew. Bed size was 30-inch raised beds with black plastic mulch and drip irrigation. Soil tests were taken at each location prior to planting. Hortnova 9FA netting (Fred C. Gloeckner & Co., Harrison, NY) was used to support 'Irish Eyes' transplants.

Data collected included time to flower, harvest date, flower diameter, stem length, number of secondary blooms and floral quality. Floral quality was based on size, uniformity, and color.

Experiment II: Photoperiod, Mulch and Row Cover

R. hirta 'Irish Spring' seed were sown into 288-sized plug trays on 13 January 2005. Bottom heat was used to enhance germination and early development. On 17 February 2005, plugs were potted into 8.9 cm (3.5-inch) containers (SVD 350, T.O. Plastics, Clearwater, MN) using Sungro LA4 Mix Aggregate Plus. One week later, on 24 February, plants were divided into two groups. One group received 35-day light treatment, as in experiment 1 and the other group remained in ambient light.

Sixty-four transplants of each light treatment were planted in the field at the Northeast MS Branch Experiment Station in Verona, MS and the Mayhew Tomato Farm in Mayhew. In each location, the field was laid out in 4 blocks of raised beds consisting of 4 treatments including perforated polyethylene row cover with black plastic mulch, perforated polyethylene row cover over bare ground, black plastic mulch, and bare ground for a total of 16 plots. Three

plants of each light treatment (lighted or not-lighted) were planted in each mulch/row cover treatment. Wire hoops were used to support the 1.1 mil, clear, perforated, polyethylene row cover. An 18-inch stake was driven into the middle of each plot to support a Hobo H8 Pro Series Data Logger (Onset Computer Corp., Bourne, MA 02532) for recording soil and air temperatures. The units were situated approximately 12 inches above the soil surface. An attached wire probe placed approximately two inches below the soil surface recorded soil temperature.

Measurements were taken at first flower and included number of days from transplanting to harvest, stem length (height measured from harvest cut to receptacle), inflorescence diameter and floral quality. Treatments were arranged in the field using a randomized complete block design and analyzed by SAS Proc GLM (SAS Institute, Inc., Cary, NC). Floral quality was based on size, uniformity and color. Terminal bloom diameter was statistically analyzed using a randomized complete block design. Only uniform blooms with acceptable color were harvested.

Experiment III: Postharvest Life

Postharvest life of fresh cut flowers was measured relative to duration of floral quality. A quality rating method was employed that measured the length of days postharvest the flowers retained acceptable color, turgidity, and overall appearance. Flowers were evaluated at room temperature in distilled water. Flowers were harvested before 10:00 a.m., tagged for identification purposes, placed directly in tap water and moved to the laboratory on campus. In the laboratory, flowers were transferred to quart jars containing distilled water and stored at room temperature.

CHAPTER IV

RESULTS

Experiment I: Photoperiod and Exogenous GA₃

Night interruption (NI), prior to a single exogenous GA₃ application, increased stem length of 'Indian Summer'. Plants receiving the greater number of days NI were significantly taller than those with lesser NI. The tallest plants received the higher number of days NI and the shortest plants received the least number of days NI (Table 1).

Table 1. Effect of Days of Night Interruption (NI) on Stem Length (SL) of *Rudbeckia hirta* L. 'Indian Summer' at Transplanting Prior to Gibberellic Acid Application

Cultivar	NI (days)	SL (cm)
Indian Summer	0	11.3d
	21	15.6c
	28	21.3b
	35	34.3a
LSD ($p \geq 0.05$)		5.2

Means with the same letter are not significantly different

GA₃, alone or in combination with NI had on days to first flower (DFF), terminal bloom diameter (TBD), or stem length (SL) for 'Indian Summer' at Verona (Table 2). Time

to first flower ranged from 30 days to 41 days after transplanting. Some plants remained in rosette stage for the duration of the test. These included treatments with no exogenous GA application and up to 21 days night interruption.

When GA was applied at a solution rate of either 150 or 300 ppm to plants receiving less than 28 days of night interruption there were no blooms produced. It appeared that these plants may have had some stem elongation but died shortly after transplanting. Only those receiving at least 28 days NI with or without GA applications produced acceptable blooms. Overall, mean time to harvest was 38 days with a range of 30 to 41 days (Table 2).

Terminal bloom diameter ranged from 7.6 cm to 14.0 cm. Overall, mean bloom diameter was 10.5 cm. Stem length ranged from 48.1 cm to 71.1 cm. Overall, mean stem length was 61.2 cm (Table 2).

Table 2. Effect of Gibberellic Acid (GA₃) Alone and in Combination with Days of Night Interruption (NI) on Days to First Flower (DFF) from Transplanting, Terminal Bloom Diameter (TBD), Stem Length (SL) and Uppermost Internode Length (UIL) for *Rudbeckia hirta* L. 'Indian Summer' at Verona, MS

GA ₃ (ppm)	NI	DFF	TBD	SL (cm)
0	0	-*	-	-
0	21	-	-	-
0	28	41	9.5	50.2
0	35	36	9.6	48.1
150	0	-	-	-
150	21	41	7.6	63.5
150	28	41	14.0	65.4
150	35	33	8.9	54.6
300	0	-	-	-
300	21	41	10.8	71.1
300	28	41	12.7	67.6
300	35	30	10.8	69.8
LSD (p ≥ 0.05)	NS	NS	NS	NS

x "-" denotes no blooms harvested

NS - Results were not significantly different.

There was also no significant effect of GA₃ on days to first flower (DFF), terminal bloom diameter (TBD), or upper internode length (UIL) for 'Indian Summer' at Mayhew (Table 3). Days to first flower (DFF) harvest ranged from 19 to 38 days (mean = 32) after transplanting. Plants without exogenous GA and up to 21 days NI remained in rosette stage. Only one plant bloomed without GA and 28 days NI but was not included in the data since stem length was only 21 cm (9.5 inches). All others receiving 150 or 300 ppm GA in combination with less than 28 days NI either died or had

poorly formed inflorescence (Table 3). Terminal bloom diameter ranged from 10.2 cm to 13.0 cm. Overall, mean bloom diameter was 11.4 cm.

There were significant differences in stem lengths among treatments at Mayhew (Table 3). Plants in treatments 300-21 (refers to 300 ppm GA₃ plus 21 days NI) and 300-28 were significantly taller than those of treatments 0-35, 150-21 and 150-28 at the .05% probability level. Plants in treatments 300-21, 300-28, and 300-35 were significantly taller than those of treatment 150-21 and 150-28 but not taller than plants treated with 150 ppm GA and 35 NI (150-35).

Plants treated with 150-21 were the shortest but not significantly shorter than those treated with 0-35 or 150-28. They were, however, shorter than those treated with 150-35.

Stem lengths ranged from 38.1 cm to 68.1 cm. Mean stem length over all treatments was 54.2 cm. Mean internode length was 13.9 cm. The range of internode lengths was from 4.4 cm to 20.3 cm (Table 3).

Table 3. Effect of Gibberellic Acid (GA₃) Alone and in Combination with Days of Night Interruption (NI) on Days to First Flower (DFF) from Transplanting, Terminal Bloom Diameter (TBD), Stem Length (SL) and Uppermost Internode Length (UIL) for *Rudbeckia hirta* L. 'Indian Summer' at Mayhew, MS

GA ₃ (ppm)	NI	DFF	TBD (cm)	SL (cm)	UIL (cm)
0	0	-*	-	-	-
0	21	-	-	-	-
0	28	-	-	-	4.4
0	35	34.3	13.0	49.1bcd	13.0
150	0	-	-	-	-
150	21	38.0	12.0	38.1d	11.4
150	28	34.0	10.8	42.2dc	14.0
150	35	28.3	10.4	53.8abc	12.0
300	0	-	-	-	-
300	21	38.0	12.0	68.1a	16.5
300	28	31.5	10.2	64.8a	20.3
300	35	19.3	11.4	63.2ab	18.8
LSD (p ≥ 0.05)	NS	NS	NS	15.1	NS

Means with the same letter are not significantly different

x "-" denotes no blooms harvested

NS = not significant

For 'Irish Eyes', there were differences in plant height corresponding to days of Night Interruption (NI) (Table 4). Night interruption duration increased plant height after exogenous GA application. Plants receiving 35 NI were taller than the remaining treatments. There was no difference between 21 and 28 NI. Shortest plants received 0 NI. Height ranged from 22.7 cm to 54.7 cm.

Table 4. Effect of Days of Night Interruption (NI) on Stem Length (SL) of *Rudbeckia hirta* L. 'Irish Eyes' at Transplanting Prior to Gibberellic Acid Application

Cultivar	NI	SL (cm)
Irish Eyes	0	22.7c
	21	34.3b
	28	38.0b
	35	54.7a
LSD ($p \geq 0.05$)		5.2

Means with the same letter are not significantly significant.

There were significant differences in days to first flower of *R. hirta* 'Irish Eyes' depending on treatment at Verona. All treatments were equally effective except 0-35, 150-35 and 300-35 which resulted in the least number of days to first flower (Table 5). Range of days to first flower is 16.5 to 37 days with overall mean of 28.2 days.

There were no significant differences in terminal bloom diameter (TBD), number of secondary blooms (NSB), or stem length (SL) at Verona (Table 5). Bloom diameter ranged in size from 8.6 to 12.4 cm. Overall mean bloom diameter was 9.5 cm. Stem length ranged from 37.8 cm to 68.1 cm. Overall mean stem length was 57.2 cm (Table 5).

Table 5. Effect of Gibberellic Acid (GA₃) Alone and in Combination with Days of Night Interruption (NI) on Days to First Flower (DFF) from Transplanting, Terminal Bloom Diameter (TBD), Number of Secondary Blooms (NSB), and Stem Length (SL) for *Rudbeckia hirta* L. 'Irish Eyes', Verona, MS

GA ₃ (ppm)	NI	DFF	TBD (cm)	NSB	SL (cm)
0	0	36.0a	12.4	10.5	54.8
0	21	36.6a	10.2	14.3	52.9
0	28	37.0a	9.6	10.0	61.0
0	35	22.5cde	10.6	6.8	55.7
150	0	27.0abcd	8.0	5.5	37.8
150	21	27.0abcd	8.0	6.8	54.8
150	28	27.0abcd	9.2	9.0	61.0
150	35	16.5e	8.6	5.8	62.7
300	0	32.3abc	11.4	6.8	48.2
300	21	34.0ab	10.4	9.0	64.8
300	28	25.5bcde	6.6	11.5	64.1
300	35	17.0de	8.8	8.0	68.1
LSD (p > 0.05)		10.3	NS	NS	NS

x "-" denotes no blooms harvested

Means with the same letter are not significantly different

There were significant differences in days to first flower (DFF) of *R. hirta* 'Irish Eyes' at Mayhew (Table 6). All treatments were equally effective except 0-0, which resulted in the longest DFF and 0-35, 150-35, and 300-35, which resulted in the shortest DFF (Table 6). Range of days to first flower is 11.3 to 30.5 days with a mean of 21.1 days.

Table 6. Effect of Gibberellic Acid (GA₃) Alone and in Combination with Days of Night Interruption (NI) on Days to First Flower (DFF) from Transplanting, Terminal Bloom Diameter (TBD), Number of Secondary Blooms (NSB), Stem Length (SL) and Uppermost Internode Length (UIL) for *Rudbeckia hirta* L. 'Irish Eyes', Mayhew, MS

GA ₃ (ppm)	NI	DFF	TBD (cm)	NSB	SL (cm)	UIL (cm)
0	0	30.5a	10.2	8.6	50.8cde	15.4
0	21	25.5ab	7.1	8.6	52.4cde	16.0
0	28	22.3b	9.2	8.5	59.5abcd	22.0
0	35	11.3d	7.6	5.8	59.7abcd	16.5
150	0	25.0ab	8.3	5.0	40.0e	17.8
150	21	23.7b	5.7	9.5	63.5abc	17.1
150	28	20.0bc	8.5	6.0	59.3abcd	13.3
150	35	12.8d	8.4	4.0	70.2a	15.4
300	0	19.7bc	6.8	5.3	48.7de	19.7
300	21	22.5b	7.3	10.0	65.4ab	
300	28	24.5ab	7.4	6.6	57.6abcd	12.3
300	35	15.3cd	7.6	2.3	63.3abc	15.6
LSD (p \geq 0.05)	6.4		NS	NS	13.4	NS

Means with the same letter are not significantly different.

GA₃ at 150 ppm plus 35 NI resulted in the greatest stem length and GA₃ at 150 ppm plus 0 NI resulted in the least stem length, and did not differ from 0-0 and 0-21 or 300-0. The remaining treatments were equally effective. There were no differences in uppermost internode length for 'Irish Eyes' at Mayhew (Table 6).

There were no differences in TBD or NSB at Mayhew (Table 6). Bloom diameter ranged from 5.7 to 10.2 cm. Overall mean bloom diameter was 7.8 cm.

Experiment II: Photoperiod and Mulch/Row Cover

There was a difference in the height of plants with respect to lighted versus unlighted transplants prior to setting in the field (Table 7). Plants receiving 35 NI were taller than those receiving 0 NI. Average height of lighted plants was 24.6 cm and that of unlit plants was 10.0 cm.

There was no difference in days to first flower (DFF), or terminal bloom diameter (TBD) among treatments at Verona (Table 8). Treatments included lighted vs. unlighted plants field grown in one of 4 mulch treatments including row cover with black plastic mulch (RCBM), row cover with bare ground (RCBG), black plastic mulch (BM) or bare ground (BG). Days to flower ranged from 40 to 41 days after transplanting. Within all flowering treatments the average was 40.5 days to flower. Plants that received 35 NI flowered. Unlit plants remained in rosette stage for the duration of the experiment.

At Verona, 75% of plants produced blooms in RCBM plots, 92% from RCBG, 50% from BM and 42% from BG. Terminal bloom diameter ranged from 12.0 cm to 12.9 cm with an overall mean diameter of 12.4 cm (Table 8).

Table 7. Comparison of Lighted vs. Unlighted Greenhouse-grown *Rudbeckia hirta* L. 'Irish Spring' Seedlings After 35 Days of Night Interruption

Treatment	Height (cm)
Lighted	24.6a
Unlighted	10.0b
LSD ($p \geq 0.05$)	2.6

Means with the same letter are not significantly different.

There was a difference in stem length at Verona (Table 8). All treatments were equally effective in increasing stem length compared to bare ground (BG) (Table 8). Stem length over all treatments was 43.0 cm. Range of stem length was 36.4 cm to 50.3 cm.

There were no differences in days to first flower (DFF) or stem length (SL) among treatments at Mayhew (Table 9). Days to flower ranged from 31 to 34 days after transplanting with a mean of 33.2 days to flower. Plants that received 35 NI flowered. Unlit plants remained in rosette stage for the duration of the experiment. At Mayhew, 100% of potential blooms were harvested from RCBM plots, 92% from RCBG plots, 58% from BM plots and 33% from BG plots (Table 9).

Table 8. Effect of Row Cover/Mulch Treatment on Days to First Flower (DFF) After Transplanting, Terminal Bloom Diameter (TBD), Stem Length (SL), Percent Blooms Harvested (BH), for *Rudbeckia hirta* L. 'Irish Spring' at Verona, MS

Treatment	DFF	TBD (cm)	SL (cm)	BH (%)
Row Cover/Black Mulch	40.0	12.5	43.5ab	75ab
Row Cover/Bare Ground	40.0	12.9	50.3a	92a
Black Plastic Mulch	41.0	12.0	42.0ab	50b
Bare Ground	41.0	12.0	36.4b	42b
LSD ($p \geq 0.05$)	NS	NS	8.4	36.5

Means with the same letter are not significantly different.

There was a difference in diameter of terminal flowers at Mayhew (Table 9). Blooms in the bare ground treatment (BG) were larger than row cover/bare ground (RCBG) and black mulch (BM). There was no significant difference in bloom size for row cover/black mulch (RCBM) and row cover/bare ground (RCBG). There was no significant difference in bare ground (BG) and RCBM. Bloom diameter was least in the black mulch treatment. Bloom diameter at Mayhew ranged from 10.4 cm to 12.7 cm. Overall, the mean bloom diameter was 11.7 cm. Overall mean stem length was 40.6 cm and range was 38.8 cm to 44.1 cm.

Table 9. Effect of Row Cover/Mulch Treatment on Days to First Flower (DFF) After Transplanting, Terminal Bloom Diameter (TBD), Mean Stem Length (SL), and Percent Blooms Harvested for *Rudbeckia hirta* L. 'Irish Spring' at Mayhew, MS

Treatment	DFF	TBD (cm)	SL (cm)	BH (%)
Row Cover/Black Mulch	34.7	11.9ab	44.1	100a
Row Cover/Bare Ground	31.4	11.7b	39.3	92a
Black Plastic Mulch	34.8	10.4c	40.2	58b
Bare Ground	34.8	12.7a	38.8	33b
LSD ($p \geq 0.05$)	NS	0.86	NS	32

Means with the same letter are not significantly different.

Both row cover treatments were equally effective in obtaining maximum surface air temperature (MSAT) compared to the control (BG). Neither row cover treatment, however, was different from black mulch (BM). Maximum surface air temperatures ranged from 31.5 to 43.3 C (Table 10).

Mean air temperature (MAT) was increased by RCBM and RCBG but not by BM as compared to control (BG). Treatments RCBM and RCBG had significantly warmer air temperatures than treatments without row cover (BM, BG). Air temperatures ranged from 17.0 C to 19.8 C (Table 10).

Table 10. Effect of Row Cover/Mulch Treatment on Maximum Surface Air Temperature (MSAT) and Mean Air Temperature (MAT) on *Rudbeckia hirta* L. 'Irish Spring' at Mayhew, MS

Treatment	MSAT ($^{\circ}$ C)	MSAT ($^{\circ}$ F)	MAT ($^{\circ}$ C)	MAT ($^{\circ}$ F)
Row Cover/Black Mulch	43.3a	110.0a	19.8a	68.0a
Row Cover/Bare Ground	42.4a	108.0a	19.3a	67.0a
Black Plastic Mulch	37.4ab	99.0ab	17.4b	63.0b
Bare Ground	31.5b	89.0b	17.0b	63.0b
LSD ($p \geq 0.05$)	7.8		1.4	

Means with the same letter are not significantly different

Experiment III: Postharvest Life

No significant differences were found for postharvest life (days) for any of the three cultivars of *Rudbeckia hirta*. This includes 'Indian Summer', 'Irish Eyes' (Table 11) and Irish Spring (Table 12). Postharvest life for blooms of 'Indian Summer' was 8.7 days. Range of means was from 3 days to 17.6 days. Postharvest life for blooms of 'Irish Eyes' was 9.6 days. Range of means was 2.5 days to 13 days. Postharvest life for blooms of 'Irish Spring' was 10.6 days. Range of means was 5.5 days to 13.4 days.

Table 11. Effect of Gibberellic Acid (GA₃) Alone and in Combination with Days of Night Interruption (NI) on Postharvest Life in Days (PLD) of *Rudbeckia hirta* L. 'Indian Summer' and 'Irish Eyes', Mayhew, MS

GA ₃ (ppm)	NI	'Indian Summer'	'Irish Eyes'
		PLD	PLD
0	0	- ^x	10.6
0	21	-	8.5
0	28	4.0	3.5
0	35	10.2	16.8
150	0	-	10.0
150	21	3.0	2.5
150	28	7.0	13.0
150	35	14.0	10.2
300	0	-	11.5
300	21	7.0	-
300	28	7.0	11.3
300	35	17.6	8.0
LSD (0.05)	NS	NS	NS

x "-" denotes no blooms harvested

Table 12. Effect of Gibberellic Acid (GA₃) Alone and in Combination with Days of Night Interruption (NI) on Postharvest Life in Days (PLD) of *Rudbeckia hirta* L. 'Irish Spring', Mayhew, MS

Treatment	PLD
Row Cover + Black Plastic Mulch	11.8
Row Cover + Bare Ground	13.4
Black Plastic Mulch	12.0
Bare Ground	5.5
LSD (p ≥ 0.05)	NS

CHAPTER V

DISCUSSION

Experiment I: Photoperiod and Exogenous GA₃

Young plants in the greenhouse responded to extended photoperiod by increasing in height in direct relation to the length of the treatment period. Before receiving exogenous GA application and before transplanting to the field, those plants with the least NI were the shortest and those with the most NI were the tallest. Height increased incrementally with the tallest plants having received 35 NI. Plants receiving 0 NI were still in the rosette stage with no visible stem elongation. These results agree with findings of Garner and Allard (1924), Murneek (1936), Orvos and Lyons (1989), Harkess and Lyons (1994b), and others.

Response to NI was very similar for both *R. hirta* 'Indian Summer' and 'Irish Eyes'. However, 'Irish Eyes' seedlings grew at a more rapid rate and were taller than 'Indian Summer' seedlings at the time of transplanting. The average height of 'Irish Eyes' seedlings was 37.4 cm compared to 20.6 cm for 'Indian Summer'. In addition, all

'Irish Eyes' seedlings had grown out of the rosette stage and formed a flower stem of varying lengths. Many were "leggy" and required careful handling during transport and subsequent synthetic net-wire support in the field. Without the additional support, plants would have been susceptible to breakage and falling over. 'Indian Summer' stems were more substantial and required no such additional support in the field.

Garner and Allard (1924) noted plant axis development with *Rudbeckia bicolor* after two weeks of 18-hour photoperiod extension using incandescent light. The fact that stems of the same cultivar had statistically differing heights related to NI concurred with Murneek's (1936) findings that stem elongation could not be induced but was rather sustained or maintained under long photoperiods. Since the daily photoperiod was the same for all light treatments it would appear to be the number of NI that is a critical factor for stem length.

Days to First Flower for *R. hirta* 'Indian Summer'

The purpose of the experiment was to determine if *Rudbeckia hirta* cultivars could be forced to bloom earlier than they do naturally. Planting date in Verona was 1 April 2005, and on 5 April 2005, in Mayhew. In order to gain a market advantage, the plants would need to bloom by mid-May. A target date of 8 May 2005 was set to correspond with Mother's Day. In order to meet this initial target date, plants would need to bloom within 38 days of planting in Verona and within 33 days of planting at Mayhew.

At Verona, the average was 38 days to flower for 'Indian Summer' with a range of 30 to 41 days. This was very close to the target date and considerably earlier than normal. Although there was no significant difference in days to harvest due to treatment it is important to note that no plants flowered without at least 28 days of supplemental lighting or 150 ppm GA and 21 days of supplemental lighting.

Orvos and Lyons (1989) found the longer the plant perceives the inductive photoperiod, the faster it came into flower. Although flowering was earlier than normal, there was no significant difference in time to flower as exposure to inductive photoperiod increased. Harkess and

Lyons (1994) reported floret primordial did not initiate in *Rudbeckia hirta* even after 20 long days.

At Mayhew, the average was approximately 32 days to flower for 'Indian Summer' with a range of 19 to 38 days. At this location, nothing flowered with less than 35 days of supplemental lighting except for treatments with 150 ppm GA. In this case, the plant bloomed with a minimum of 21 days of supplemental lighting. This was seen at both locations with the apparent effect of 150 ppm GA substituting for about one week of lighting. Although there was no significant difference in days to flower at either location it might be noted that fewest days to harvest belonged to plants treated with 300 ppm GA and 35 NI or 150 ppm GA and 35 NI in that order. Evans and Lyons (1988) reported that GA₄ + 7 substituted for long days and promoted flowering under short days for *Gaillardia x grandiflora*.

In both locations, there were two treatments, 150 ppm GA and 0 NI and 300 ppm GA and 0 NI that failed to yield blooms. Plants were damaged and had a burned appearance. It is likely that the volume of hormone solution applied to the rosette-staged plants resulted in desiccation of leaf tissue from exogenous GA application.

Terminal Bloom Size for *R. hirta* 'Indian Summer'

There was apparently no treatment effect related to NI or GA application on size of terminal blooms. Overall, blooms were smaller than anticipated at both locations. Blooms averaged 10.5 cm at Verona and 11.4 cm at Mayhew. Indian Summer blooms typically range in size from 15.24 cm (6 in.) to 20.32 (8 in.) with an average of 17.78 cm (Harkess and Lyons, 1993a). Cooler than optimal temperatures after transplanting may be the cause. A few blooms were distorted and therefore not included in the data. Only those flowers with acceptable form, color and overall appearance were included.

Another factor that may have affected bloom size and flower development had to do with a problem in the greenhouse. At one point, about midway in the greenhouse production phase, leaf tissue and stem growing points on many plants began to show signs of distortion. This led to examination for spider mites and other causal organisms. Samples were sent to the MSU Plant Pathology Lab. Tissue samples were also taken. No apparent cause for the distortion could be credited to insect or disease. However, the tissue sample revealed that calcium content of leaf tissue was in the low level range for *Rudbeckia* at

.86% (Mills and Jones, 1996). Other micronutrients were also below sufficiency levels (Mg, S, Fe, Mn, Zn, Cu, and B). Nitrogen, phosphate and potassium all measured in the sufficiency range yet at high levels (Table 13).

Symptoms also matched calcium deficiency insomuch that young leaf margins became necrotic and distorted (Nelson, 2003b). The growing points of floral stems were also affected. Stem tips became blackened and somewhat distorted. In some cases, the bud would excise. If the problem had been recognized sooner calcium nitrate would have been applied to help remedy the situation.

In another situation, terminal buds were lost in some plants. Moisture from overhead watering collected on terminal buds. Plants were in very close proximity to each other and air movement was poor deep in the foliage even with HAF fans working at intervals throughout the day and night. Excess moisture seems to have been the cause for additional bud loss.

Table 13. Tissue Analysis of *Rudbeckia hirta* L. Cultivars Taken During Greenhouse Production Phase, Prior to Transplanting

Crop	Sample ID	(%)						(PPM)				
		N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	Bo
<i>Rudbeckia</i>	'Irish Eyes'	7.02	0.68	3.3	0.86	0.49	0.15	83	41	28	5	39
<i>Rudbeckia</i>	'Indian Summer'	7.04	0.65	3.5	0.58	0.37	0.12	68	28	27	4	32

Stem Length at First Harvest for *R. hirta* 'Indian Summer'

Acceptable stem length may be debatable from florist to florist but it is reasonable to accept 46 cm, approximately 18 inches, as a minimum stem length (Stevens, 1998). 'Indian Summer' has a potential height of approximately 91 cm (Odenwald and Turner, 1996).

There was no significant difference in stem length at Verona. Nevertheless, all treatments that flowered had acceptable stem lengths. By comparison, the longest stem length was approximately 70 cm and the shortest stem length was 48.1 cm.

At Mayhew, stem lengths were significantly different. At this location, a notable comparison is that of three treatments including 300 ppm GA and 21, 28, and 35 NI (tallest stems) with that of the shortest treatment, 150 ppm GA and 21 NI. The increased level of GA, from 300 to 150, is the only apparent difference between the two 21 NI treatments. There is also no significant variability between the three highest GA ppm treatments and 150-35, that is, the lower GA concentration and the highest NI was comparable to the higher GA concentration with 21, 28 and 35 NI.

There is no significant difference in the lower range of heights including 0-35, 150-28 and 150-21. These are quite similar. It is important to point out, however, stem length of treatment 0-35 (49.1cm) is above the acceptable minimum of 46cm and the other two treatments are not (42.2 cm and 38.1 cm, respectively). All other treatments at Mayhew were above the acceptable minimum stem length.

Length of Uppermost Internode for *R. hirta* 'Indian Summer'

Measuring the height of the uppermost internode was intended to be a relative measure of the effect of GA treatment on the stem. At Verona, there was no significant difference in mean stem length. At Mayhew, significant differences in mean height were found (see previous section for discussion).

Although there were significant differences in mean stem length at Mayhew, there was not a significant difference in the length of stem between the highest node and the base of the floral structure. This would indicate that some other area on the stems of plants at Mayhew were more greatly affected or there is a more equal distribution of growth along the entire stem than was previously expected.

It is implied on the product label that the area targeted by the exogenous GA application should be sprayed directly for best effect. Therefore, with this implication comes the possible explanation that the uppermost internode, being only partially exposed to the initial spray, may not be the primary area of stem elongation.

Days to First Flower for *R. hirta* 'Irish Eyes'

Days to first flower at Verona were significantly different. The most dramatic difference occurred between plants receiving 35 NI and 0, 150 or 300 ppm GA or 28 NI and 300 ppm GA versus those treatments receiving 0, 21, or 28 NI only. There was, however, no significant difference in the treatment that received only 35 NI (0-35) and the other top 3 treatments where GA was included.

Treatment 150-35 had the least number of days to harvest (16.5). This was significantly fewer days to harvest than 8 of the remaining treatments, yet not quicker to flower than one with no GA and 35 days night interruption (0-35). This may indicate an advantage to using GA when less than 35 NI is employed. The 35 NI treatment was only better than those treatments with 28 NI or less and 21 NI with 300 ppm GA.

At Mayhew, a similar pattern developed for days to flower from transplanting. Treatments with 35 NI and 0, 150, or 300 ppm were significantly quicker to flower than all other treatments with the exception of 300-35. The treatment that took the longest to flower was the control with no NI and no GA (0-0). However, it was no slower to flower than 0-21, 150-0 or 300-28.

At both locations those treatments that included 35 NI flowered with the least number of days. As previously described, these treatments were sooner to flower than the majority of the others. Keeping in mind the goal of earliness, at Verona, the goal was to bloom within 38 days of planting. All treatments made this goal with the highest days to flower being 37. At Mayhew, the goal was to flower within 33 days after transplanting. The treatment with the highest number of days to harvest was cut at approximately 31 days after transplanting. Therefore, all treatments, regardless of GA or NI were harvested by the target date.

This information may lead to the question of the need for photoperiod extension or GA treatment since the control was harvested within the desired time frame for this cultivar. However, there was a distinct advantage to using

NI and GA to maximize earliness and height of harvested flowers.

Terminal Bloom Size for *R. hirta* 'Irish Eyes'

There were no significant differences in bloom size at either Verona or Mayhew. Blooms were, on average, smaller than those of 'Indian Summer' but that is to be expected. The bloom display is a spray and terminal flowers are an indication of quality but not necessarily the only measure of that characteristic. Secondary blooms and flower buds accompanied each terminal flower. These secondary blooms numbered as low as 2 or 3 or as high as 50 (300-21, Verona).

Stem Length at First Harvest for *R. hirta* 'Irish Eyes'

At Mayhew, there were significant differences in stem length. Eight of twelve treatments were significantly taller than GA at 150 ppm plus 0 NI (150-0). This was the shortest treatment and the only one that fell below the 45.7cm (18 inch) minimum height. All other treatments at Mayhew exceeded this minimum.

The top four treatments, 300-35, 150-21, 300-21 and 150-35 (listed in ascending order by height) were taller than the four shortest treatments at Mayhew. The four at

the bottom of the list were 150-0, 300-0, 0-0, and 0-21, listed in ascending order according to height. Both levels of GA and 0 NI follow a similar pattern in 'Irish Eyes' as in 'Indian Summer'. This is likely related to the rate of GA and the size of the plant at time of application. The other two shortest treatments received no growth hormone and 21 NI or less.

There was no difference among the four shortest treatments nor was there a significant difference in height among the top four treatments. In addition, there was no significant difference in treatments of no GA plus no NI (0-0) or no GA plus 21 NI (0-21) when compared to all other treatments except the two tallest treatments (150-35 and 300-21).

The top four treatments, although taller than the bottom four, as previously mentioned, are not significantly different from treatments of 0 GA and 28 NI (0-28) or 0 GA and 35 NI (0-35) or 150 ppm GA and 28 NI (150-28) or 300 ppm GA and 28 NI (300-28).

At Verona, there were no differences in stem length. However, a similar pattern in stem length was noted. Treatment 150-0 was at the bottom of the height chart and less than the minimum height of 45.7 cm (18 inches).

Results at Mayhew would indicate that there are some treatments superior to others but no particular combination of GA and NI was consistently better than no treatment at all. However, we may say that either 150 or 300 ppm GA in combination with more than 0 NI are important for maximizing stem length potential.

Experiment II: Photoperiod and Mulch/Row Cover

Plant Height Comparison of Lighted vs. Unlighted

R. hirta 'Irish Spring' Prior to Transplanting

Differences in plant height were measured just prior to transplanting. Lighted plants were more than twice the height of unlit plants. Much like 'Indian Summer', unlit plants were still in rosette stage. This pattern would continue such that only lighted plants would eventually bloom by the mid-May target date. It would appear that lighting alone is the most significant factor affecting height for these two treatments. No plant growth hormone was applied.

Days to First Flower for *Rudbeckia hirta* 'Irish Spring'

The purpose of the experiment was to determine if *Rudbeckia hirta* 'Irish Spring' could be forced to bloom

earlier than they do naturally with the influence of mulch and row cover variables. Planting date in Verona was 1 April 2005 and on 5 April in Mayhew. A target date of 8 May was set, Mother's Day. In order to meet this initial target date, plants would need to bloom within 38 days of planting in Verona and within 33 days of planting at Mayhew.

At both locations, there was no statistical difference in days to first flower (DFF) for any of the mulch/row cover treatments. Only plants receiving NI in the greenhouse bloomed in the field by the end of the experiment. Only one treatment, row cover/bare ground (RCBG) at Mayhew, had a mean harvest date less than the establishment 33-days-to-harvest target.

At Verona, days to first flower (DFF) for all treatments, was no more than two or three days after the target harvest date. At Mayhew, row cover with bare ground treatment was ready for harvest approximately 3 days before the others. That placed it approximately 2 calendar days ahead of other treatments in reference to the target harvest day.

Harvest dates for both locations are well ahead of natural bloom cycles. At harvest time, plants that did not receive extended photoperiod during greenhouse production had no noticeable stem elongation or flower bud initiation.

The target date for this experiment was missed for the majority of treatments by one to three days. However, blooms harvested mid-May are likely to have greater market potential than those harvested during the normal bloom cycle based on overall consumer demand (Monthly Retail Trade Survey, 2005).

Another important observation refers to the number of blooms harvested per treatment. Given on a percentage of potential blooms harvested by the end of the experiment at Mayhew, 100% of potential blooms were harvested from the row cover black mulch treatment (RCBM), 92% of potential blooms harvested from RCBG, 58% were harvested from black mulch (BM) and only 33% of potential blooms were harvested from bare ground planting (BG). At Verona, 75% were harvested from RCBM, 92% from RCBG, 50% from BM and 42% from BG. Higher mean air temperatures would seem to be the main reason for the higher percentage of blooms harvested in row cover plots.

Terminal Bloom Size for *R. hirta* 'Irish Spring'

At Verona, treatment seemed to have little effect on mean bloom diameter. Mean diameter for all treatments was 12.0 cm or greater to 12.9 cm. Blooms at both locations were well formed and attractive regarding uniformity and color.

At Mayhew, there were statistical differences in bloom size. Largest blooms were harvested from the bare ground treatment. Blooms harvested under both row cover treatments were very similar in size. Smallest blooms were harvested from the black mulch treatment.

The absence of statistical differences at Verona and the largest blooms in the bare ground treatment at Mayhew question the necessity of cold protection for this cultivar when planted in early April after the danger of frost is past. However, when percent blooms harvested is considered it appears that the higher mean temperatures were a major factor in more rapid floral development in row cover plots.

Stem Length at First Harvest for *R. hirta* 'Irish Spring'

Mean length of stems was significantly different by treatment at Verona. At this location, the tallest stems were harvested from plants grown with row cover on bare

ground (RCBG). Mean stem length of 45.7 cm was only obtained in RCBG treatments. With a mean stem length of 50.3, the flower stems grown with row cover plus bare ground were just above the minimum. Although it would be much more desirable at greater lengths, stems grown with RCBG were tall enough for market.

Although RCBG was taller than bare ground (BG) plants, it was not taller than row cover/black mulch or black mulch alone. Likewise, the row cover with black mulch and black mulch treatments were no taller than bare ground. It would seem obvious that temperature played a key role but air and soil temperatures were not measured at Verona due to lack of additional Hobo data recorders.

At Mayhew, there was no significant difference in mean stem length. In addition, all stems were below the minimum height of 45.7 cm. This is a point of concern and questions the use of this plant for early cut flower production. The row cover/black mulch treatment was just under the minimum at 44.1 cm. This borderline height may be usable in the trade but is still undesirable. Flower size, color and quality are exceptional, however, and may compensate for use with less than minimum length stems.

Effect of Row Cover/Mulch on Soil and Air Temperature

There was less soil and air temperature effect than might be expected. There were no significant differences in the range of soil temperature, mean minimum soil temperature or mean maximum soil temperature.

At Mayhew, where these temperatures were measured, there were no significant differences in stem length or days to harvest but there were differences in terminal bloom size and percent of blooms harvested. Terminal blooms from plants grown on bare ground were largest. At Verona, bare ground yielded flowers the same size as or within one centimeter of the other treatments.

The use of row cover, and or mulch, did not apparently affect soil temperature enough to make a difference in plant growth and development and any resulting affect on bloom size.

There were significant differences in both mean and maximum air temperatures at Mayhew. The warmest mean and maximum air temperatures were recorded under row cover where heat would be expected to be given up more slowly than where row cover was absent.

The row cover was perforated in order to moderate air temperatures and prevent excessive heat buildup. Air

temperatures in both row cover treatments were warmer than bare ground but not warmer than black mulch. Higher temperatures had little effect to increase bloom size since flowers were slightly larger on bare ground grown plants.

Nevertheless, adding row cover over bare ground resulted in mean stem lengths that were significantly better at Verona and provided the only stems with mean length above the accepted minimum. Plants on bare ground (BG) had stems that were shortest at Verona.

At both locations there were differences in the percentage of potential blooms harvested. Highest percentage of harvested blooms occurred where row cover was used and the lowest percentage from bare ground.

For bloom size or days to harvest, it may not be necessary to use perforated polyethylene cover, but for meeting stem length requirements and maximizing the number of blooms harvested, row cover is indeed advantageous.

Experiment III: Postharvest Life

There was much variation within cultivars that resulted in a lack of significant difference among treatments. There was a wide range of days of post harvest life. For example, the treatment of 150 ppm GA and 21 NI

declined in quality significantly at 3 days following harvest. However, mean treatment 300 ppm GA plus 35 DEPP maintained quality appearance for slightly over 17 days. However, due to variability within treatments, no significant difference established. The average days of postharvest life for 'Indian Summer' was almost 9 days.

When choosing species for cut flower use it is desirable to have a postharvest life of at least 7 days (Stevens, 1998). Two of the treatments measured less than 7 days. Three treatments had a mean postharvest life of 7 days. The treatments with the highest mean postharvest life were each of the 35-day treatments (0-35, 150-35 and 300-35).

Similar results were obtained for 'Irish Eyes'. No significant difference occurred between treatments yet some had a postharvest life less than seven days (0-28 and 150-21). All other treatment means were above the minimum.

There was no significant difference in postharvest life of 'Irish Spring'. However, three of the four had mean postharvest life in excess of ten days. These were treatments including row cover with mulch, row cover over bare ground or black mulch alone. The bare ground treatment had a mean post harvest life of only 5.5 days.

CHAPTER VI

SUMMARY AND CONCLUSION

Effect of Limited Induction Photoperiod on Greenhouse-grown Transplants

Extending day length with supplemental lighting had a significant effect on all three cultivars. Seedling *Rudbeckia hirta* responded to limited induction photoperiod by increasing in height according to the number of days with 4-hours of night interruption. For 'Indian Summer', height increased as the number of NI increased. The response of 'Irish Eyes' was similar in that plants receiving no NI were the shortest plants and those receiving 35 days NI were the tallest prior to transplanting. There was no difference between 21 and 28 NI treatments.

'Irish Spring' followed a similar pattern. Although there were only two lighting regimes, 35 or 0 days with night interruption, lighted plants were significantly taller than unlighted plants prior to field transplanting.

Supplemental greenhouse lighting increased the height of plants in comparison to the control. For fresh cutflower production, this study shows the benefit of "preconditioning" *Rudbeckia hirta* cultivars with supplemental lighting to insure continued floral development, earliness to bloom and adequate stem length when field-grown under short day conditions.

Floral Quality Summary

Floral quality was good for all cultivars although some of the earliest harvested 'Indian Summer' and 'Irish Eyes' blooms were slightly deformed with unequal size ray and disc flowers. Calcium deficiency occurred in the greenhouse and is believed to be the causal agent for reduction in quality. Symptoms first observed in the greenhouse included leaf and bud necrosis and deformation. This reduced the number of plants available for field transplanting. In future experiments, calcium nitrate may be used to reduce the likelihood of this occurrence. The deficiency seemed to be more pronounced in 'Irish Eyes' possibly since they grew more rapidly than 'Indian Summer'. 'Irish Spring' seedlings were affected least. Plants were younger than the other two cultivars at the time of

transplanting. There was no loss of floral quality in 'Irish Spring' due to calcium deficiency.

Postharvest Life Summary

The average postharvest life for all three cultivars was within the acceptable range and above minimum expectations of 7 days. No significant differences among treatments were detected. The range of postharvest days was quite broad for each cultivar suggesting more variability than might be expected. 'Indian Summer' had the greatest variability with blooms lasting for as few as 3 days to as many as 17.6 (14.6 day range). 'Irish Spring' had the least variability with blooms lasting from as few as 5.5 days to as many as 13.4 (7.9 day range).

Early Flowering of *R. hirta* 'Indian Summer'

For early flowering, 'Indian Summer' should receive a minimum of 35 days of night interruption unless Gibberellic acid is applied. When 150 ppm GA₃ is used, plants may flower earlier with as little as 21 days of night interruption. This may lower the cost of production by reducing kilowatt usage. Although stem lengths across treatments were very similar there may be an advantage to using 300 ppm GA₃ to maximize stem length.

Plants bloomed with fewer than 28 NI only when GA₃ was applied at either 150 or 300 ppm and a minimum of 21 NI. Treatments with either rate of GA₃ and 0 NI failed to bloom.

Days to first flower is the principle factor for measuring earliness. In this study, the target date was May 8th. At Verona, only 'Indian Summer' plants receiving 35 NI alone or in combination with GA were, on average, harvested prior to the target date. At Mayhew, those receiving 35 NI and either 150 or 300 ppm GA were harvested prior to the target date. The 35 NI and 0 ppm GA missed the targeted harvest date by one day.

There was no difference in terminal bloom diameter at either location. Bloom size was acceptable and floral quality overall was good for all harvested treatments.

Mean stem lengths for 'Indian Summer' at Verona were similar. Of those treatments that bloomed all had acceptable stem lengths. At Mayhew, there were significant differences among treatments. Those with 300 ppm GA and at least 21 NI (300-21, 300-28, 300-35) exceeded 60 centimeters in height, ranging from 63.2 - 68.1 cm (25 - 27 inches).

Early Flowering of *R. hirta* 'Irish Eyes'

There were significant differences in days to first flower (DFF) among treatments of 'Irish Eyes' at both locations. At each site, all treatments, including the control (0-0) bloomed before the established target date.

At Verona, earliest blooms were harvested 16.5 days after transplanting from treatment 150-35 and 17.0 days after transplanting from treatment 300-35. Other treatments noted for comparable quick harvest included treatment combinations of 0 ppm GA and 35 NI (0-35), and 300 ppm GA and 28 NI (300-28). There were no differences in terminal bloom diameter at either location.

At Mayhew, earliest harvest was collected from treatment combinations of 150 ppm GA and 35 NI (150-35) at 12.8 days after transplanting, 0 ppm GA and 35 NI (0-35) at 11.3 days after transplanting and 300-35 at 15.3 days after transplanting. These were not significantly different from treatments 300-0 (19.7 days) or 150-28 (20.0 days).

Mean stem length of 'Irish Eyes' treatments were similar at Verona but significantly different at Mayhew. The most obvious point of separation of treatments at Mayhew occurred between 150 ppm GA and 35 NI (150-35) and those with no GA and 21 NI or less (0-0, 0-21) or either

rate of GA and no supplemental lighting (150-0,300-0). Measurement of uppermost internode indicated that the height differential is not attributable to the uppermost internode alone.

'Irish Eyes' shows the greatest potential for multi-stem harvest. The growth habit is more spray-like providing multiple blooms per harvested stem and prolific early season production. However, there was no difference in the number of blooms produced per plant by treatment at either location.

Early Flowering of *R. hirta* 'Irish Spring'

Days to first flower were greater for 'Irish Spring' at Verona than at Mayhew. There was no difference in DFF based on treatment. However, only those plants receiving supplemental lighting via night interruption (NI) bloomed. Considering earliness and the established target date for harvest of 38 days at Verona and 33 days at Mayhew, only one treatment at one location succeeded.

The combination of row cover and bare ground at Mayhew yielded 'Irish Spring' blooms that were on average harvested within 33 days. All lighted treatments were harvested before plants grown under natural day length.

Only lighted 'Irish Spring' plants bloomed in the field. Terminal bloom diameter was significantly different only at the Mayhew location. Plants grown without mulch or row cover had the largest blooms. However, all treatments produced large, attractive, high quality blooms.

Mean stem length for 'Irish Spring' at Verona was significantly different. The combination of row cover and black mulch (RCBM) was taller than those grown on bare ground (BG). At Mayhew, mean stem lengths were similar.

Max surface air temperatures (MSAT) were higher in row cover plots than on bare ground. Maximum surface air temperatures under row cover with or without black mulch were higher, on average, than bare ground but not significantly warmer than black mulch alone. Black mulch alone did not provide max air temperatures greater than bare ground.

Mean air temperatures in row cover treatments were, on average, warmer than either black mulch or bare ground. Higher mean air temperatures likely contributed to the higher percent of flowers harvested from row cover plots. This is an important result indicating the value of row cover in fresh cut flower production.

Terminal bloom diameter was actually larger for plants grown on bare ground (BG) at Mayhew than those grown on black mulch (BM) or row cover over bare ground (RCBG).

Future Work

In the future, it would be valuable to investigate nutritional requirements of long day plants when greenhouse-grown with supplemental lighting. It would seem that higher rates of fertilizer along with those containing a source of calcium might be needed to insure high quality transplant production. Nutritional requirements of plants grown under supplemental lighting might be greater than those grown under normal greenhouse lighting conditions.

It would also be important to evaluate long day plants when lighted in the field after normal greenhouse production practices. Night interruption lighting in the field may allow for earlier transplanting and may reduce the need for more specialized fertilization practices during the greenhouse phase of production.

Other long day plants could be investigated to evaluate their performance as fresh cutflowers when preconditioned with supplemental lighting prior to field transplanting. Long day cultivars suitable for fresh

cutflower production might also be found that are better able to withstand cool spring temperatures.

Research might be conducted that would employ multiple applications of Gibberellic acid to promote greater stem length. Since only one application of GA_3 was used for this experiment it would be interesting to evaluate the effect of multiple applications once transplants are set in the field.

Research with other phytohormones, for example, cytokinins, could be investigated to observe whether substances such as Benzylaminopurine might encourage branching in field grown cutflowers.

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